Quarterly Update June 30/1977

(NASA-CR-158532) LITERATURE REVIEW OF HYDROGEN ENERGY. A BIBLIOGRAPHY WITH ABSTRACTS Quarterly Update, 30 Jun. 1977 (New Mexico Univ.) 22 p

N79-76979

Unclas

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# QUARTERLY LITERATURE REVIEW

# OF

# HYDROGEN ENERGY

# A BIBLIOGRAPHY WITH ABSTRACTS

QUARTERLY UPDATE
APRIL-JUNE 1977

a product of

THE ENERGY INFORMATION PROGRAM

A cooperative effort

of

THE COLLEGE OF ENGINEERING

and

THE TECHNOLOGY APPLICATION CENTER
A DIVISION OF THE INSTITUTE FOR APPLIED RESEARCH SERVICES (IARS)

THE UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO

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## PREFACE

HYDROGEN ENERGY is a continuing bibliographic summary with abstracts of research and projections on the subject of hydrogen as a secondary fuel and as an energy carrier. The first volume was published in January, 1974 and is cumulative through December of 1973. Additional copies are available from the Technology Application Center, as are the quarterly update series for 1974, 1975, 1976 and the first quarter of 1977.

This update to HYDROGEN ENERGY cites additional references identified during the second quarter of 1977. It is the second in a 1977 quarterly series intended to provide "current awareness" to those interested in hydrogen energy.

For the reader's convenience, a series of cross indexes are included which track directly with those of the cumulative volume. See "Guide to Use of the Publication."

A library containing some of the articles and publications referenced in this update and the cumulative volume has been established and the Center will, on a cost-recovery basis, aid readers to obtain copies of any cited material. Although a considerable effort has been made to insure that the bibliography is complete, readers are encouraged to bring any omissions to the attention of this Center.

The Technology Application Center is one of six Industrial Application Centers established by NASA's Technology Utilization Program to evaluate and disseminate new technology to the general public and commercial business.

# INTRODUCTION

The paucity of technical papers in the hydrogen energy field is evident in this quarterly issue. One plausible explanation for the lack of relevant literature is that some of the papers are being held for publication at regular forums such as the Miami Hydrogen Conferences and the IECEC.

One of the editors (Dr. M. Natarajan) will be leaving this organization forthwith and would like to take this opportunity to thank all those who are interested in Hydrogen Energy for their support and cooperation.

We urge the readers of the publication to either send us results of their work or of work they know about that may have eluded our search for future inclusion in the document.

Dr. Kenneth E. Cox
Professor, Chemical & Nuclear Engineering Dept.

Dr. Mani Natarajan
Technology Application Center

# GUIDE TO USE OF THIS PUBLICATION

A number of features have been incorporated to help the reader use this document. They consist of:

-- A TABLE OF CONTENTS listing general categories of subject content and indexes. More specific coverage by subject keyword, title, author, or corporate source is available through the appropriate index.

-- CITATION NUMBERS assigned to each reference. These numbers, with the prefix omitted, are used instead of page numbers to identify references in the various indexes. They are also used as TAC identifier numbers when dealing with document orders so please use the entire (prefix included) citation number when corresponding with TAC regarding a reference. An open ended numbering system facilitates easy incorporation of subsequent updates into the organization of the material. In this system, numbers assigned to new citations in each category will follow directly the last assigned numbers in the previous publication. The citation number of the last reference on each page appears on the upper right-hand corner of that page to facilitate quick location of a specific item.

-- DIVIDER PAGES at the beginning of each major sections containing the section number and title. When a subsection has no citations for that particular update, a divider page with the subsection number and the notice "No Citations in This Category" is inserted where that subsection would normally appear.

-- A REFERENCE FORMAT containing the TAC citation number, title of reference, author, corporate affiliation, reference source, contract or grant number, abstract, and keywords. The reference source tells, to the best of our knowledge, where the reference came from. If from a periodical, the reference source contains the periodical's title, volume number, page number, and date. If for a report, the reference source contains the report number assigned by the issuing agency, number of pages, and date.

--An INDEX OF AUTHORS alphabetized by author's last name. A reference's author is followed by the reference's citation number. For multiple authors, each author is listed in the index.

--An INDEX OF PERMUTED TITLES/KEYWORDS affords access through major words in the title and through an assigned set of keywords for each citation. A reference's title is followed by the reference's citation number. In the indexes, all the words pertaining to a reference are permuted alphabetically. Thus, the citation number for a reference appears as many times as there are major title words or keywords for that reference. The permuted words run down the center of an index page. The rest of the title or keywords appear adjacent to a permuted word. Since a title or set of keywords is allowed only <u>one</u> line per permuted word the beginning, the end, or both ends of a title or set of keywords may be cut off; or, if space permits, it will be continued at the opposite side of the page until it runs back into itself. A # indicates the end of a title or set of keywords while a / indicates where a title or set of keywords has been cut off within a line.

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# I. GENERAL: CONCEPTS, CONFERENCES, SURVEYS, REVIEWS

H77 10279 INTERNATIONAL CONFERENCE ON HYDROGEN AND ITS PROSPECTS

Soper, W.G., (Office of Naval Research London, England), 22 p., Dec 31, 1976, ONRL-C-49-76, AD-A036 936/3WE

Papers from the international conference 'Hydrogen and its Prospects' Liege, Belgium, 15-18 1976, are reviewed for their contribution to future production and utilization of hydrogen as a fuel. Principal emphasis is placed upon the production of hydrogen by electrolysis and thermochemical decomposition of water, and upon the comparison of these processes with synthetic fuel production from fossil resources. Other topics discussed include hydrogen storage and its use as fuel in automobiles and aircraft.

(PRODUCTION, UTILIZATION, FUEL, ELECTROLYSIS)

H77 10280 HOPES FLY HIGH FOR NEW HYDROGEN PROCESSES

Kohn, P.M., Chemical Engineering, V 84, N6, Mar 1977

The abundance of hydrogen makes it attractive as a potential major source of fuel. But how can it be produced economically on a large scale? Researchers are hoping to find an answer in electrolytic, thermochemical or hybrid systems.

(FUEL, ECONOMICS, ELECTROLYSIS, THERMOCHEMICAL, CYCLE)

H77 10281 ELECTROCHEMISTRY IN THE SOLAR ECONOMY

Appleby, A.J., (Laboratoire d'Electrolyse du C.N.R.S., France), From "Trends in Electrochemistry," Bockris, Rand, Welch, eds., Plenum '77

Since the leadtime for the widespread application of any new technology is of the order of thirty years, valid discussion of the above topic is restricted to the 21st century. Any predictions concerning energy utilization, or the state of society, at that time are necessarily hazardous, especially in view of the recent Ford Foundation Report on the energy future of the United States to the end of the present century. This report, which represents an extrapolation of current energy technology and conventional economic analysis, envisages a wide range of scenarios for what remains of the present fossil-fuel economy, involving vastly different predictions concerning energy consumption and G.N.P.

(ENERGY TECHNOLOGY, UTILIZATION, ECONOMICS)

# II. PRODUCTION

## H77 20568 HYDROGEN FROM THE WIND - A CLEAN ENERGY SYSTEM

Dubey, M., (Lockheed-California Company, Burbank, CA), Technical Program for the 1977 Helioscience Institute - An International Solar/Energy Conference, Northrop University, CA, May 2-4, 1977

Hydrogen is a clean, non-polluting fuel. It can be used as a substitute for methane gas or petroleum products to provide both heat or power. It is also an important feedstock for many chemical processes, the most important of which is the manufacture of ammonia. Natural gas, the primary source for hydrogen, is becoming costly as demand has outstripped supply and the discoveries of new natural gas sources have diminished. Though hydrogen can be manufactured from other energy resources, such as coal, oil, and nuclear reactions, these are much more costly. Thus, there is a growing interest in alternative energy resources, especially ones which are replenishable, such as solar radiation, wind, and ocean thermal gradients. The most advanced of these is wind. All steps in the process of converting wind energy to stored hydrogen are technologically developed and being put in to practice commercially. Thus, their combination can be accomplished immediately with little risk.

(WIND ENERGY, ELECTROLYSIS, WATER)

## H77 21130 EFFICIENCIES OF ELECTROLYTIC AND THERMOCHEMICAL HYDROGEN PRODUCTION

Anon, Nature, V 253:257-258, N5489, Jan 24, 1975

Two methods not involving fossil fuels for manufacturing hydrogen have been suggested as a basis for an eventual hydrogen economy: first, electrolysis of water using nuclear (or ultimately solar, geothermal or thermonuclear) electricity and, second, thermochemical cycles using nuclear heat, in general from a high temperature reactor. In the thermochemical processes, a series of chemical steps is envisaged that will allow the differential splitting of the $H_2O$ molecule by means of reactions at different temperatures and with appropriate thermodynamic requirements to give high efficiency.

(ENERGY LOSSES, THERMODYNAMICS)

## H77 23633 SOLAR ENERGY CONVERSION OF WATER TO HYDROGEN

Anon, (Univ of NC, Greensboro), Platinum Met Rev, V 20:123, N4, Oct 1976

A potentially most important discovery of a means of producing hydrogen from water by photochemical cleavage has been announced by a team led by Professor David G. Whitten of the Department of Chemistry in the University of North Carolina. The reaction, which could have a major impact on future energy requirements, involves a ruthenium complex, tris(2, 2'-bipyridine)ruthenium (II). Spread as a monolayer on sheets of glass, in contact with water and irradiated by light, these complexes give rise to a steady stream of molecular hydrogen and oxygen.

(PHOTOCHEMICAL, RUTHENIUM, OXYGEN)

H77 23634 NEAR-UV PHOTON EFFICIENCY IN A $TiO_2$ ELECTRODE: APPLICATION TO HYDROGEN PRODUCTION FROM SOLAR ENERGY

Desplat, J.L., (Cent d'Etud Nucl de Saclay, Gif-sur-Yvette, France), J Appl Phys, V 47:5102-5104, N11, Nov 1976

An n-type (001) $TiO_2$ electrode irradiated at 365 nm was tested under anodic polarization: a saturation current independent of pH and proportional to light intensity has been observed. Accurate measurements of the incident power lead to a 60% photon efficiency. A photoelectrochemical cell built with such an electrode, operated under solar irradiation without concentration, produced an electrolysis current of 0.7 mA/cm$^2$ without applied voltage.

(POLARIZATION, PHOTOELECTROCHEMICAL, CURRENT)

H77 23635 ENERGY CONVERSION VIA PHOTOELECTROLYSIS

Nozik, A.J., (Allied Chem Corp, Morristown, NJ), 26 refs, Proc of 11th Intersoc Energy Convers Eng Conf, State Line, NV, Sept 12-17, 1976

Photoelectrolysis is a new energy conversion scheme in which optical energy is converted into chemical energy using photoactive semiconducting electrodes in a photoelectrochemical cell. The process is shown to involve multiphoton effects so that use can be made of visible light. A model for photoelectrolysis is presented which encompasses the mechanism and the energetics of the process. Application of photoelectrolysis to the generation of hydrogen from water using solar radiation is discussed. Data on energy conversion efficiencies are presented for several semiconductor electrode systems. These semiconductors have been studied in the form of single crystals and polycrystalline thin films. The economic viability of photoelectrolysis as a potential scheme for the generation of hydrogen is discussed and comparisons are made with conventional hydrogen generating processes.

(SEMICONDUCTOR, ELECTRODE, EFFICIENCY)

H77 23636 PHOTOASSISTED ELECTROLYSIS OF WATER: CONVERSION OF OPTICAL TO CHEMICAL ENERGY

Wrighton, M.S., Bolts, J.M., Ellis, A.B., Kaison, S.W., (MIT, Cambridge, MA), 42 refs, Proc of 11th Intersoc Energy Convers Eng Conf, State Line, NV, Sept 12-17, 1976

Photoelectrochemical cells for the photoelectrolysis of $H_2O$ to $H_2$ and $O_2$ are described. Such cells can, in principle, be used to efficiently convert solar energy to chemical energy in the form of the electrolysis products. The basic principles, potential advantages, and current problems associated with photoelectrochemical cells as energy conversion devices are outlined.

(SOLAR CELLS, ELECTROCHEMISTRY)

H77 23637 SOLAR PRODUCTION OF VEHICULAR FUELS

Cox, K.E., (Chemical and Nuclear Engineering Department, University of New Mexico, Albuquerque, NM), Technical Program for the 1977 Helioscience Institute - An International Solar/Energy Conference, Northrop University, CA, May 2-4, 1977

The rapid depletion of our domestic fossil fuel resource base has been and continues to be an issue of great concern. Shortages, curtailments, and increased dependence upon foreign sources of energy are becoming the rule rather than the exception. This study examines the role of solar energy, its conversion to hydrogen, that can be stored, as an alternative source of energy for vehicles and other end uses.

(SOLAR, HYDROGEN, ENERGY SOURCE)

H77 23638 SOLAR-THERMOCHEMICAL HYDROGEN PRODUCTION

Schuster, J.R., (General Atomic Company, San Diego, CA), Technical Program for the 1977 Helioscience Institute - An International Solar/Energy Conference, Northrop University, CA, May 2-4, 1977

Solar energy, as a primary energy form, can meet many of society's needs. Where the technology exists and the economics are attractive, solar energy systems are already being successfully implemented. An example of this is the solar heating and cooling of buildings. Considerable attention is also being given to the application of solar energy for producing electricity. Particularly in producing electricity, however, there is a major problem with solar energy; diurnal, interruptible sunlight makes energy storage a necessity. Due to the cost of energy storage and the cost of backup generating capability, central station solar electric plants are projected to have only limited application, and only in the intermediate load and peaking categories. For a solar energy plant to be base loaded it will have to have the capability for storing energy for periods in excess of 24 hr.

(SOLAR, STORAGE, DECOMPOSITION)

# III. UTILIZATION

## H77 31045 6670-NEWTON ATTITUDE-CONTROL THRUSTER USING HYDROGEN-OXYGEN PROPELLANT

Gordon, L.H., (NASA, Lewis Research Center, Cleveland, OH), NASA-TM-X-3523, May 1977

As part of a program to develop a reusable, attitude-control propulsion system for the space transportation system, a flight weight, gaseous-hydrogen - gaseous-oxygen attitude-control thruster assembly was tested. This report describes the NASA testing of one of four contractor-built thrusters to obtain data on cyclic life, thermal and hydraulic characteristics, pulse response, and performance. The basic thruster components were tested in excess of 51,000 pulses and 660 seconds, steady state, with no degradation of the 93 percent characteristic exhaust velocity efficiency level. Nominal operating conditions were a chamber pressure of 207 $N/cm^2$ (300 psia), a mixture ratio of 4.0, a pulse width of 100 ms, and a pulse frequency of 2 Hz.

(ROCKET ENGINES, FUEL, PROPULSION)

## H77 32073 EMISSIONS AND TOTAL ENERGY CONSUMPTION OF A MULTI-CYLINDER PISTON ENGINE RUNNING ON GASOLINE AND A HYDROGEN-GASOLINE MIXTURE

Cassidy, J.F., (NASA, Lewis Research Center, Cleveland, OH), NASA-TN-D-8487, May 1977

An experimental program using a multicylinder reciprocating engine was performed to extend the efficient lean operating range of gasoline by adding hydrogen. Both bottled hydrogen and hydrogen produced by a research methanol steam reformer were used. These results were compared with results for all gasoline. A high-compression-ratio, 7.4-liter (472-in.$^3$) displacement production engine was used. Apparent flame speed was used to describe the differences in emissions and performance. Therefore, engine emissions and performance, including apparent flame speed and energy lost to the cooling system and the exhaust gas, were measured over a range of equivalence ratios for each fuel. The results were used to explain the advantages of adding hydrogen to gasoline as a method of extending the lean operating range. The minimum-energy-consumption equivalence ratio was extended to leaner conditions by adding hydrogen, although the minimum energy consumption did not change. All emission levels decreased at the leaner conditions. Also, adding hydrogen significantly increased flame speed over all equivalence ratios. Engine performance and emissions with hydrogen from the methanol reformer were about the same as those with bottled hydrogen.

(ENGINES, FUEL CONSUMPTION, EMISSION, HYDROGEN)

# IV. TRANSMISSION, DISTRIBUTION, AND STORAGE

## H77 40433 THERMAL PERFORMANCE OF AN INTEGRATED THERMAL PROTECTION SYSTEM FOR LONG-TERM STORAGE OF CRYOGENIC PROPELLANTS IN SPACE

DeWitt, R.L., Boyle, R.J., (NASA, Lewis Research Center, Cleveland, OH), NASA-TN-D-8320, May 1977

It was demonstrated that cryogenic propellants can be stored unvented in space long enough to accomplish a Saturn orbiter mission after a 1200-day coast. The thermal design of a hydrogen-fluorine rocket stage was carried out and the hydrogen tank, its support structure, and thermal protection system were tested in a vacuum chamber. Heat transfer rates of approximately 23 W were measured in tests to simulate the near-Earth portion of the mission. Tests to simulate the majority of the time the vehicle would be in deep space and sun-oriented resulted in a heat transfer rate of 0.11 W.

(MULTILAYER INSULATION, SPACE STORAGE, LIQUID HYDROGEN)

## H77 43076 THEORY OF HYDROGEN IN LIQUID AND SOLID METALS

Mainwood, A., Stoneham, A.M., (UKAEA Research Group, Harwell, Atomic Energy Research Establishment), 16 p., Dec 1975, AERE-TP-644

A method is outlined for calculating the interatomic forces between isolated hydrogens and their host metal atoms. The method uses a semi-empirical molecular-orbital approach for a suitable cluster of atoms, with the empirical parameters fitted to experimental potential energy curves for diatomic molecules. Parameters suitable for hydrogen in liquid or solid Li and Na are given. The method is applied to calculation of solvation energies of hydrogen in liquid Li and Na, where satisfactory agreement with experiment is obtained. Detailed potential energy surfaces are also found for H in solid Na and estimates are made of local mode frequencies, the stability of the tetrahedral sites, lattice relaxation, and effective charges and atomic radii. Neither the anionic nor the protonic limit is appropriate. It has not proved possible to describe the potential energy surfaces in terms of a sum of two-body and volume-dependent terms alone.

(POTENTIAL ENERGY, LITHIUM, SODIUM)

## H77 43077 "HYDROGEN IN METALS"

Elsevier Sequoia, S.A., Lausanne, bound volume, 508 p., 1976, Proceedings of The Meeting On "Hydrogen in Metals", University of Birmingham, United Kingdom, Jan 5-6, 1976

More than 40 papers are printed in this book. They cover a number of sophisticated and elaborate experimental investigations and theoretical modelling studies in the field of Hydrogen in Metals. Some important findings which were not accessible fifty years ago are reported and revealed in this volume. Most promising are those along the following two lines: First: Means of introducing protons into metals by electrolysis at temperatures as low as 200$^{o}$K as a particularly effective device for injecting H atoms to higher saturation, with consequent greater expansion of the host lattice than is feasible at ambient temperatures; Second: The role of hydrogen in metals in molten rather than the crystalline state.

(MODEL, ELECTROLYSIS, LOW TEMPERATURE)

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